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Cleaning of Municipal Waste Incinerator Flue Gas in Europe

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16. ABSTRACT The paper gives an overview of a substantial ongoing air pollution control program in West Germany, as it relates to emission of acid gases and other pollutants from municipal refuse incineration. It details emission regulations, control means used, and technical advancements accomplished and foreseen. It gives results and the approximate effectiveness of various controls in reducing acid gas, trace organic, trace heavy metal, and particulate matter emissions. Available data indicate that lime spray dryer/ESP and spray dryer/fabric filter systems can attain 70-90% acid gas removal and 97% or more control of dioxins and furans, while limiting mercury emissions to about 0.01-0.07 mg/N-cu m (dry). In comparison, some wet scrubber systems can attain 90-plus % acid gas removal with substantial removal of NOx and comparable control of dioxins and furans, while possibly providing consistently lower mercury emissions.

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Incinerators	Stationary Sources	
Municipalities	Municipal Waste	05D
Waste Disposal		
Flue Gases		21B
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ABSTRACT

This paper presents an overview of a substantial ongoing air pollution control program activity in West Germany as it relates to emission of acid gases and other pollutants from municipal refuse

incineration. Details are given of emission regulations, control means used, and technical advancements accomplished and foreseen. Test results and the approximate effectiveness for various controls in reducing acid gas, trace organic, trace heavy metal, and particulate matter emissions are presented. Available data indicate that lime spray dryer/ESP and spray dryer/fabric filter systems can attain 70-90% acid gas removal and 97% or more control of dioxins and furans while limiting mercury emissions to about 0.01 to 0.07 mg/Nm³ (dry). In comparison, some wet scrubber systems can attain 90+% acid gas removal, have potential for removal of NO_x and can achieve control of dioxins and furans comparable with semi-dry scrubbers while possibly providing consistently lower mercury emissions.

INTRODUCTION

Significant design and operating experience has been gained in Europe over the past 20 years relating to municipal waste incinerator facilities. Approximately 180 such incineration systems, each with a capacity in excess of 200 tonnes per day of municipal refuse, already exist in Europe, principally in West Germany, France, The United Kingdom, Switzerland, Italy, Sweden, Belgium, The Netherlands, and Denmark (1). West Germany is the leading European country in the amount of municipal waste incinerated, the use of heat recovery facilities, and the number and efficiency of flue gas cleaning facilities. It is anticipated that availability of this European technology will be beneficial in the U.S.A., since approximately 125 municipal incinerator (resource recovery) projects are in the conceptual stage of development here (2).

WEST GERMAN EMISSION REGULATIONS

Although incinerator flue gas emission limits for acid gases have been imposed by the federal government since 1974, a more stringent regulation was introduced through the West German "Clean Air Code" (TA Luft) enacted in February 1986 (3). These new federal emission limits, expressed in mg/Nm³* (approximate ppmv) at 11% O_2 concentration are: SO_2, 100 (35); NO_x, 500 (250); CO, 100 (80); HCl, 50 (31); HF, 2 (2.2); and total solid particulate, 30 (equivalent to 0.012 gr/dscf). Moreover, group 1 inorganic particulate (cadmium, mercury, and thallium) is limited to 0.2 mg/Nm³; group 2 (arsenic, cobalt, nickel, selenium, and tellurium), to 1 mg/Nm³; and group 3 (including lead), to 5 mg/Nm³. Additionally, limits are imposed on three different groups, differentiated by level of toxicity, of organic vapor and carcinogenic compounds. Table 1, originating from Reference 4, has been adjusted to give an updated comparison of several of the specific West German emission limits with requirements in the U.S.A. and Sweden.

GROSS EMISSION LEVELS

Typical ranges of actual flue gas pollutant emission concentrations from pre-TA Luft incinerator installations in West Germany (5) are given in Table 2. For comparison, emission limits cited above are also shown in this table.

FLUE GAS CLEANING METHODS

The earliest European incinerators were equipped with electrostatic precipitators (ESPs), but wet scrubbers have more

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* N denotes "German Standard" conditions: 1.013 bar, 0°C, no moisture (dry gas).

recently supplemented ESPs extensively in West Germany so as to limit acid gas emissions. To avoid the resulting liquid effluent discharge, spray dryers are now also introduced upstream of a wet alkali scrubbing facility. In this arrangement, the wet scrubber liquid effluent is the liquid feed to the spray dryer. Due to the high HCl concentration in the flue gas and the hygroscopic characteristics of the dry $CaCl_2$ formed from it, acid gases (HCl and SO_2) are absorbed at high efficiency by dry scrubbing systems like spray dryer absorbers or dry injection systems using lime as sorbent. Although the uncontrolled NO_x emissions are typically no more than 300mg/Nm³, substantially less than the new TA Luft limit of 500 mg/Nm³ (6), some new incinerator installations are providing for NO_x removal because of site-specific factors, including anticipation of more stringent local/provincial emission regulations. In the most recent installations, particulate emissions are frequently being controlled by the use of fabric filters in lieu of ESPs.

Wet Scrubbers

Spray tower and venturi wet scrubbers are commonly used downstream of ESPs to remove HCl, HF, and SO_2. HCl and HF are frequently removed in the first scrubber stage (or pre-scrubber), and SO_2 is collected in a separate second scrubber stage. A heat exchanger can be included downstream of the SO_2 scrubber to condense water vapor from the water-saturated, cleaned flue gas. This new concept, which is termed subcooling, reduces the visible steam-plume discharge and improves removal of submicrometer (submicron) particles and metallic vapors. Some recent gas cleaning applications

have a wet scrubber system (see Figure 1) downstream of a spray dryer that receives the wet scrubber effluent and converts it to a solid waste. The spray dryer in this configuration is designed to dry only the wet scrubber effluent; it is not designed for significant removal of acid gases.

The system shown in Figure 1 can be modified to remove NO_x. This will be discussed in the section on post-combustion NO_x control.

Spray Dryer Absorber Scrubbers

In the common semi-dry (wet/dry) system design illustrated in Figure 2, the raw flue gas is contacted with a cloud of fine slaked-lime slurry droplets from a rotary atomizer or dual-fluid nozzles. Employed in conjunction with a downstream fabric filter or ESP, HCl, SO_2, and fine particulates can be removed efficiently and effectively.

Dry Lime Injection

Effective dry absorption of acid gases is possible through pneumatic injection (7) of hydrated lime solely or with recirculated dust-catch into flue gas cooled to 110-170°C (230-335°F), as shown in Figure 3. A circulating fluid-bed absorption system (see Figure 4) is also used for dry absorption in incinerator applications, providing significantly increased sorbent residence time upstream of an ESP.

Major European Installations in Operation

In the results of a mail survey (8) that obtained information on 30 European waste-to-energy facilities in commercial

operation using dry scrubbing and/or fabric filtration, many applications of fabric filters, semi-dry (spray dryer) scrubbers, and dry absorption (dry injection) systems are given and illustrate the extensive use of these types of equipment. This survey indicated a preference for fabric filters over ESPs for particulate matter collection. Table 3 summarizes the results of this survey and includes a number of pilot plant and very small capacity installations. Table 4 is a more complete and recent list of operational commercial systems in West Germany and reflects a substantial proportion (about 60%) of wet scrubber installations (9).

POLLUTANTS OF SPECIAL CONCERN

Particulate Matter Control

Particulate matter control for solid waste combustors is practiced in all European countries. With the traditionally used ESPs, very low emission levels are achievable, less than 45 mg/Nm³ (0.02 gr/dscf) at a high ratio of collector plate surface area to gas flow volume [i.e., in the range of 170 m²-min./m³ or min./m (52 min./ft) or greater].

Due to the fine size of incinerator particulates, normal wet venturi scrubbers are relatively ineffective for particle emission control, removing 80-95% in normal operation. Very high gas-pressure-drop is required to remove fine particulates; hence, these scrubbers are not generally used as the principal particulate control means.

Fabric filters were traditionally used sparingly because of the perceived failures caused by hot gases, spark carryover, or sticky particles. However, fabric filters can control particulate to 45 mg/Nm³ (0.02 gr/dscf) or less without operational upsets due

to varying fuel and ash composition, which may adversely affect ESPs. With the increasing use of spray dryer scrubbing systems in Europe, particulate emissions from incinerators are being controlled by highly efficient fabric filters or ESPs.

Acid Gas Control

Control of acid gases (HCl, HF, and SO_2) requires scrubbing or devices for gas/liquid or gas/solid contact. Water alone is a reasonably effective sorbent for very reactive acid gases such as HCl (and HF) in the first scrubber stage, but an alkali sorbent (i.e., control of liquid pH to 5 or higher) and additional liquid/gas contact time in a second stage are necessary for substantial SO_2 control. Sodium hydroxide rather than lime/limestone is most often used in the second wet scrubbing stage to avoid scaling. (The sodium sulfite reaction product is water soluble as contrasted with calcium sulfite, which is highly insoluble.) Highly efficient control of acid gases may be achieved by alkali wet scrubbers operating at saturation (65°C or 150°F outlet temperature), but typically requires the management of liquid blowdown.

Totally dry sorbents, on the other hand, require substantial residence time in the gas for effective acid gas control. To be effective, injection of sorbent into a duct must be complemented by a fluid-bed reactor, humidification, a fabric filter dust collector, or combinations of these (Figures 3 and 4).

Spray drying or semi-dry injection of sorbent is more effective than dry injection, with increasing acid gas control as the outlet gas temperature decreases toward the saturation temperature. It appears that the existing spray dryer absorbers at incinerators operate at an outlet temperature in the range of 120-160°C (248-320°F), while dry injection systems without gas

humidification operate at a higher gas temperature. Both the spray dryer absorber and dry sorbent injection into the flue gas duct are followed by an ESP or a fabric filter for particulate removal. Note that the performance of an ESP actually appears to improve when located downstream of a spray dryer, probably due to the reduced gas volume and gas property changes resulting at the lower gas temperature. Table 5 indicates the approximate acid gas removal capabilities of many gas cleaning system arrangements that have been applied or proposed. Since the removals given in the table are based mainly on pilot plant results, they should be applied to full scale units with caution.

Post-Combustion NO_x Control

Probably the most difficult and expensive pollutant to control is NO_x, primarily due to the low reactivity and water solubility of NO, which comprises 95% or more of the total uncontrolled NO_x. Technology recently introduced in Europe for NO_x removal includes wet absorption in either the oxidation-absorption or absorption-reduction mode.

Oxidation-Absorption. In a wet scrubber system operating downstream of a spray dryer (Figure 1), an oxidizer, such as sodium chlorite ($NaClO_2$), is added to oxidize flue gas NO to NO_2, which can be removed by a sodium-base wet scrubbing operation (1). For example, with the addition of $NaClO_2$ to the upstream venturi (HCl) scrubber and raising the pH to 3-4, some NO is oxidized to NO_2 in the first venturi scrubber (see Figure 1) and is removed in this scrubber and along with SO_2 in the following venturi scrubber.

Absorption-Reduction. Another approach used to deal with the limited reactivity of flue gas NO and its poor absorption in typical wet scrubber operations is absorption-reduction. This method of NO removal was applied at municipal refuse incinerators in Bremerhaven, West Germany, in 1987 (10). In this system, ferrous ions (Fe^{2+}) tie up NO in the liquid phase by the formation of ethylene diaminetetraacetic acid (EDTA) complexes. These complexes, in turn, react with HSO_3^- and SO_3^{2-} ions (from SO_2 absorption), leaving N_2 and sulfate (SO_4^{2-}) as reaction products. Chemical additive cost for this technology is reported to be approximately 4 to 11 DM (approximately $2 to 5 U.S.) per tonne (of waste processed) less than that for oxidation-absorption processing for NO_x removal (11).

Post-Combustion Organic Pollutant Control (Products of Incomplete Combustion, PICs)

Control of dioxins and furans, as well as other trace organic compounds, seems to be somewhat controversial, partly because the mechanism of capture is not well understood. It seems likely that their condensation and capture as particulate matter is significant, and reaction and capture by caustic reagents is also probable. These capture phenomena are best utilized by lowering flue gas temperatures, subjecting flue gas to caustic sorbent, and collecting the product in a highly efficient particulate collector. Limited data show that spray drying followed by fabric filtration is very effective for organic vapor control and superior to a spray dryer/ESP system (12). Also, lower flue gas temperatures favor increased control of organics. Reference 12, dealing with spray dryer system control of organics, is a good discussion of these

observations. Pilot plant results are summarized in Table 6, where CDD refers to chlorinated dibenzo-para-dioxins and CDF to chlorinated dibenzofurans. In this table, the low temperature is 120°C (248°F), and the high temperature is 160°C (320°F). The superiority of a sorbent dispersed on a fabric filter over that with ESP for control of dioxins and furans is evident from Table 6.

Similar high efficiency removal has been achieved by Environment Canada in pilot plant work, both with a lime spray dryer and dry lime injection into cooled/humidified flue gas upstream of fabric filtration (13). A total dioxins removal efficiency of 99.9% was demonstrated with a fabric filter inlet gas temperature of 140°C (284°F) and below. Tetra CDD, the most toxic dioxin homolog, showed the lowest outlet concentration, typically non-detectable. A minimum of 99.3% total furans removal efficiency was demonstrated at all outlet temperatures; i.e. 110-209°C (230-408°F) (13). While the dry lime injection tests were carried out over this full range of temperatures, the spray dryer tests were performed only at the 140°C (284°F) temperature.

Heavy Metals Control

The control of emissions of heavy metals, which in Europe has attracted at least as much attention as have PICs, is similar to organic pollutant control in that effective particulate capture and low flue gas temperature are major factors. Sorbents, however, are not seen to play a major role in heavy metals capture. Toxic metals enter the collectors as solids, liquids, and vapors and, as the flue gas cools, the vapor portion converts to collectible solids and liquids. However, very volatile metals, particularly mercury, are present as vapor in measureable amounts

even at the lowest outlet temperatures at which collectors are designed and operated. In general, the effectiveness of heavy metals emission control by diverse gas cleaning system designs appears to be inversely related to system outlet temperature. Testing in Sweden of a pilot wet scrubber downstream of an ESP indicated that, with subcooling of saturated flue gas to approximately 60°C (140°F), the total (particulate and gaseous) mercury emissions from a municipal waste incinerator were reduced to as low as 0.01 mg/Nm³ (dry) (14). Tests of a German municipal refuse incinerator equipped with a spray dryer followed by an ESP operating at 150°C (302°F) indicated that vapor-phase mercury emission alone was 0.05 mg/m³ or greater, (11% O_2 basis) (14). A dry injection facility serving a municipal waste refuse incinerator in Sweden, with its downstream fabric filter operating at approximately 160°C (320°F), is reported (14) to reduce particulate mercury to a typically non-detectable concentration and gaseous mercury to the range of 0.012-0.065 mg/Nm³ dry, (11% O_2 basis).

SUMMARY AND CONCLUSIONS

The European incineration market, specifically the large German (and Scandinavian) speaking area, has been pursuing the best available control technology for waste incineration flue gas cleaning for the last 5-10 years. Basically two different processes are claimed to meet this goal: (1) two-stage wet scrubbing for acid gas removal, which may use the sensible heat in the flue gas for upstream spray drying of the wet scrubber liquid waste stream, and (2) lime dry absorption in humidified flue gas or lime spray drying absorption for acid gas control, followed in either case by particulate collection using an ESP or a fabric

filter.

While wet scrubbers may achieve slightly lower emissions of acid gases (HCl, HF, and SO_2) than spray dryer absorbers, this appears less important than other emerging emission concerns, such as heavy metals, organics and, in some instances, NO_x. Spray dryer absorbers followed by ESPs or fabric filters have demonstrated satisfactory results in controlling emissions of acid gases, particulates, and heavy metals. The same appears true of wet scrubbers, even though the specific operation of an upstream spray dryer for drying the liquid effluent from the wet scrubber may require additional operational experience and data for a final evaluation. Evidence that a spray dryer absorber followed by a fabric filter baghouse, operating at a flue gas temperature of 120-140°C (248-284°F), provides efficient removal of heavy metals has been reported. Recent developments, however, suggest that a wet scrubber with additional subcooling of the flue gas may provide optimum control of emissions of some heavy metals and specifically that of gaseous mercury (Hg).

The results of some dry flue gas cleaning system tests suggest the capture of dioxins and furans by condensation and/or chemical reaction, even though the mechanism is not very well understood. Controversy still exists regarding whether the potential emissions of organics should be addressed as a combustion issue or a flue gas cleanup issue. However, it does appear prudent to limit the formation of organics in the combustor to preclude the need for their cleanup by downstream flue gas treatment and their subsequent disposal with scrubber residues. Finally, most recently the NO_x emissions from the waste incinerator (which in some complicated manner seem to be inversely related to organic emissions) have undergone study, and

potential control options via additives to the wet scrubber liquor/slurry have been identified. This may indicate that the wet scrubber, despite its relative complexity and high cost, can potentially offer novel advantages over semi-dry and dry systems. More operational experience and emission measurements are required, however, before the commercial wet NO_x removal system can be evaluated conclusively.

It appears that the specification and selection of waste incinerator flue gas cleaning systems in Germany are done mostly on a site-specific basis, considering factors such as capital cost, operational costs, scrubber waste disposal options, compliance with current emission limits, and flexibility in terms of possible retrofit to any future emission limits. Developments over the last 5-10 years suggest that the identification of an optimum flue gas cleaning system design that efficiently meets all objectives from both economic and environmental perspectives at all locations and conditions probably is unrealistic. However, the waste incineration sector has undertaken a technologically refined approach to controlling its flue gas emissions that is aimed at meeting the demands of the marketplace as well as the community.

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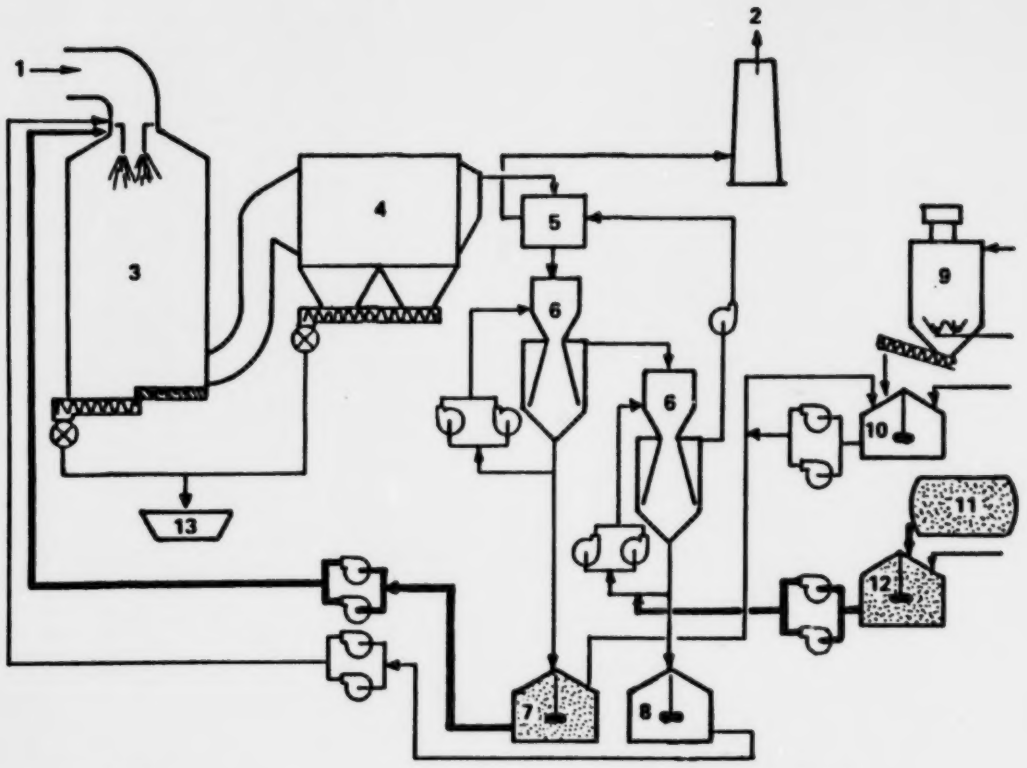


1. FLUE GAS
2. EXHAUST GAS
3. SPRAY DRYER
4. ELECTROSTATIC PRECIPITATOR OR FABRIC FILTER
5. GAS-GAS HEAT EXCHANGER
6. VENTURI SCRUBBER
7. NEUTRALIZATION TANK
8. SLUDGE TANK
9. LIME SILO
10. LIME SLAKER
11. SODIUM HYDROXIDE STORAGE
12. SODIUM AIR TANK
13. DRY WASTE

Figure 1. Semi-dry/wet scrubber (4).

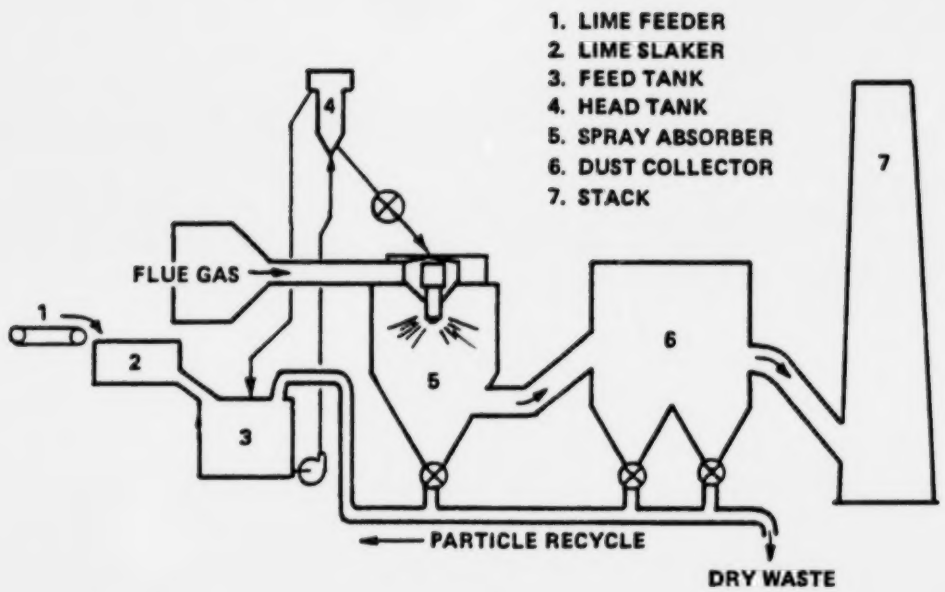
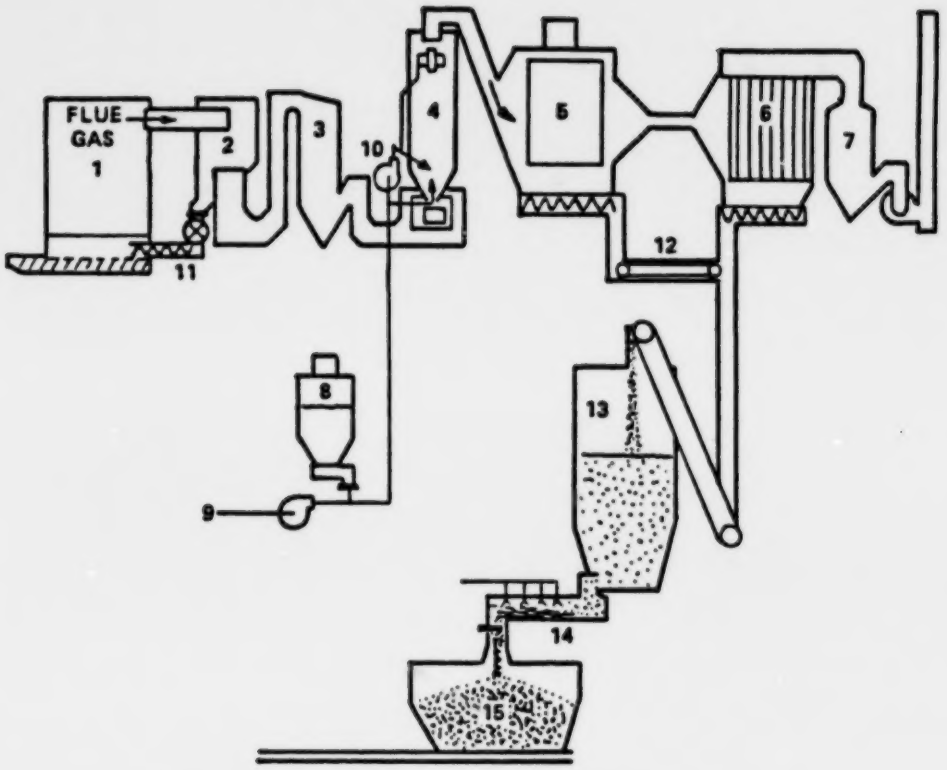
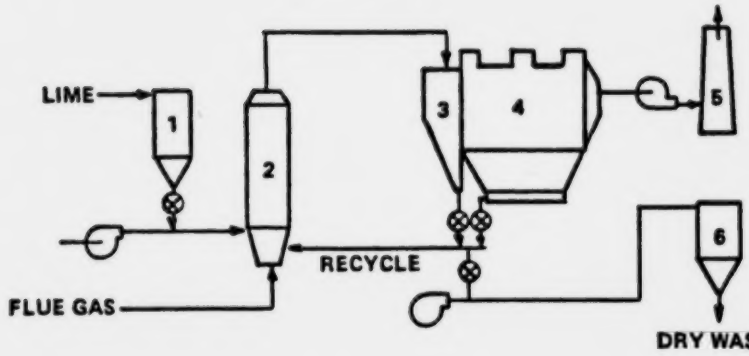


Figure 2. Spray absorption (semi-dry) process (4).



1. FURNACE AND BOILER
2. PRECOLLECTOR
3. WASTE HEAT BOILER NO. 1
4. REACTOR
5. ELECTROSTATIC PRECIPITATOR
6. FABRIC FILTER
7. WASTE HEAT BOILER NO. 2
8. LIME SILO
9. LIME FEEDING
10. LIME RECIRCULATION
11. COARSE DUST CONVEYING
12. FINE DUST CONVEYING
13. DUST SILO
14. DUST HUMIDIFIER
15. DUST BIN

Figure 3. Dry absorption system (4).



1. LIME SILO
2. REACTOR
3. CYCLONE
4. DUST COLLECTOR
5. STACK
6. WASTE SILO

Figure 4. Circulating fluid-bed absorption (dry) process (4).

TABLE 1. SELECTED EMISSIONS STANDARDS FOR MUNICIPAL WASTE INCINERATORS (4)

	U.S.[a]	California	Connecticut	Michigan	West Germany	Sweden
Solid Particulate Matter, gr/dscf (mg/m^3)	0.046 (113)	0.01[b] (25)	0.015 (37)	0.015 (37)	0.012 (30)	0.008[c] (20)
Carbon Monoxide, ppm	---	---	---	113(24-hr avg)	80	---
Hydrogen Chloride	---	30 ppmv (wet or dry scrubbers req'd)	90% reduction	90%	31 ppmv (50 mg/Nm^3)	63 ppmv (100 ng/Nm^3)
Sulfur Dioxide, ppm	---	30	170	86	35 (200 mg/Nm^3)	New SO_2 limits reduce all acids significantly
Dioxins Measured as 2,3,7,8 - tetra-chlorodibenzo-p-dioxins (TCDD)	---	[d] ---	[e] ---	---	---	Existing plants: 0.5-2.0 ng/Nm^3 New plants: 0.1 ng/Nm^3
Total Organics, mg/m^3	---	---	---	---	20	---
Mercury + Cadmium + Thallium, mg/m^3 (includes vapors)	---	---	---	---	0.2	0.08 (Hg only)
Gas Correction	12% CO_2 dry	12% CO_2 dry	12% CO_2 dry	12% CO_2 dry	11% O_2 dry	10% CO_2 dry

[a]Revised NSPS for pollutants scheduled to be proposed in 1989.
[b]California regulations permit more stringent local limits. Two state guidelines are reported: 0.01 gr/dscf (25 mg/m^3) for total solid particulates (TSP) and 0.008 gr/dscf (20 mg/m^3) for particles less than 2 μm.
[c]This limit and those below are from the Swedish Environmental Protection Board's "Temporary Emission Goals," July 1986.
[d]Pollutant control requires use of the Best Available Control Technology (BACT), although no technology has yet been specified.
[e]The use of dry gas scrubbers and baghouses is expected to improve removal over ESPs alone.

TABLE 2. WEST GERMAN EMISSION LEVELS AND LIMITS, ppmv (mg/Nm³) @ 11% O_2

Pollutant	Incinerator Gross Emissions	TA Luft Emission Limits (2/86)
HCl	30-500 (45-770)	31 (50)
HF	0.5-9 (0.4-8)	2.2 (2)
SO_2	20-220 (60-620)	35 (100)
NO^2	70-140 (150-300)	250 (500)
CO^x	40-500 (45-620)	80 (100)
Solid Particulate Matter, gr/dscf (mg/Nm³)	0.006-0.04 (15-95)	0.012 (30)

TABLE 3. EUROPEAN DRY FLUE GAS CLEANING SYSTEM SURVEY (8)

Plant Owner	Location	Waste Type	Gas Flow, 1000 cfm	Emission Control	Start-up
City of Vienna	Vienna[a]	MSW	3.5	DS	1977
Niro	Copenhagen[b]		5.3	DS	h
Kommunekemi A/S	Nyborg[b]	Haz Waste	63.1	DS/ESP	1982
Granges	Finspang[c]	MSW	8.8	DAS	1977
Suomen Ongelmajate OY	Riihimaki[c]	Haz Waste	61.4	DS/FF	1984
Stadtreinigung (MVA Ruhleben)	Berlin[d]	MSW	551	DAS	1985
Dortmund University	Dortmund[d]	MSW		DS	1976[h]
City of Dusseldorf	Dusseldorf[d]	MSW	90	DS	1980
Passavant-Werke	Dusseldorf[d]	Sludge	47.6	DS	1980
Von Roll (MVA Geiselbullach)	Geiselbullach[d]	MSW	97.7	DAS	1985
City of Hamburg	Hamburg[d]	MSW	242	DS/ESP	1978
City of Hamburg	Hamburg[d]	MSW	266	DS/ESP	1978
City of Hamm	Hamm[d]	MSW	235	DS/FF	1982
Von Roll (MVA Kempten III)	Kempten[d]	MSW	57.1	DAS/ESP & FF	1983
MVA Leverkusen	Leverkusen[d]	Ind /MSW	227	DS/ESP	1986
City of Munich	Munich[d]	MSW	470	DS	1978
Oberhausen	Oberhausen[d]	MSW	7.1	DS/FF	1979[h]
Pinneberg County	Pinneberg[d]	MSW	142	DS	1976
Accam	Busto Arsizio[e]	MSW	2.47	DAS/ESP	1983
SYSAV	Malmo[f]	MSW	159	DAS/ESP & FF	1981
SAKAB	Norrtorp[f]	Haz Waste	81.0	DS/ESP	1983
Chocolate Frey	Aarau[g]		7.1	FF	1973
Migros	Basel[g]		18.2	FF	1970
Gebr Loeb.	Bern[g]		18.2	FF	1974
Migros Genossensch.	Dierikon[g]		18.8	FF	1971
Migros	Geneva[g]		21.2	FF	1976
UI Cottendart	Neuchatel[g]		37.2	FF	1971
Migros Genossensch.	Schoenbuekl[g]		18.8	FF	1973
Hospital	Sonedan[g]		0.6	FF	1978
Yverdon	Yverdon[g]			FF	

DAS -- Dry Absorption System ESP -- Electrostatic Precipitator
DS -- Dry Scrubber FF -- Fabric Filter

[a]Austria [b] Denmark [c]Finland [d]West Germany [e]Italy [f]Sweden
[g]Switzerland [h]Pilot Unit

Note: 1000 cfm = 1,700 m³/h (at actual incinerator outlet conditions)

TABLE 4. MUNICIPAL INCINERATION FLUE GAS CLEANING PLANT SUMMARY, WEST GERMANY (June 1986 Summary)

Location	System Supplier	Gas Flow, 1000 Nm^3/h(wet)	Acid Gas Emission Control	Particulate Emission Control	Start-up
Bamberg	Babcock BSH	2x45, 1x50	WS	ESP	1978, 1981
Berlin	Flakt	7x66	DAS	ESP(/BH)	1987-89
Bielefeld-Werford	Lugar	3x132	WS	ESP	1981-82
Bremen	Lurgi	2x110, 1x150	DS	BH	1987-88
Bremerhaven	Von Roll	3x80	WS	ESP	1977, 1986-7
Darmstadt	Ciba-Geigy	1x50 (Est.)	WS		1987-88
Dusseldorf	Babcock BSH	3x140	DS	ESP	1984-85
Essen-Karnap II	Babcock BSH	4x120	WS	ESP	1987
Frankfurt/Main	Lurgi	4x120	DS	ESP(/BH)	1987
Geiselbullach	Flakt	2x42	DAS	BH	1986
Goppingen	Babcock BSH	2x62	WS	ESP	1985-87
Hagen	Babcock BSH	3x40	DS	ESP	1986-87
Hamburg 1	Babcock, HDW	2x65	DS	ESP	1985-86
Hamburg 2	Babcock, HDW	2x70	DS	ESP	
Hameln	(KW Wesertal AG)	2x60	DAS	ESP	1983
Hamm	Babcock BSH	4x50	DS	BH	1985-86
Herten	Saarberg-Hoelter	1x124	DAS	ESP	1982-83
Ingolstadt	GfE	2x56, 1x68	WS	ESP	1977, 1983
Iserlohn	Lurgi	2x50, 1x100	WS	ESP	1986
Kassel	Niro Atomizer	2x63	DS	BH	1987
Kempten/Allgäu	Flakt	1x49	DAS	BH	1984
Kiel-South	Babcock BSH	2x31, 1x62	WS	ESP	1975, 1980
Krefeld	Lugar	2x75	WS		1976
Krefeld	Babcock BSH	3x110	WS	ESP	1982
Landshut	N/A	2x51	WS	ESP	1988
Leverkusen	Niro Atomizer	2x54, 1x72	DS	ESP	1986-87
Ludwigshafen	Babcock BSH	2x54	WS	ESP	1988-89
Mannheim	Babcock BSH	2x150	WS	ESP	1987
Marktoberdorf	Lurgi	1x15	WS	BH	1974, 1985-86
Munich-North	Babcock BSH	2x140	DS	ESP	1983
Munich-South	Ciba Geigy	2x210	WS		1988

-Continued-

TABLE 4. MUNICIPAL INCINERATION FLUE GAS CLEANING PLANT SUMMARY, WEST GERMANY (June 1986 Summary) (Continued)

Location	System Supplier	Gas Flow, 1000 Nm³/h(wet)	Acid Gas Emission Control	Particulate Emission Control	Start-up
Neufahrn-Freising	Flakt	1x16 (Est.)	DAS	ESP	1987
Neunkirchen	GfE	1x26, 1x54	WS	ESP	1986-87
Neustadt/Holst.	Ciba Geigy	1x65	WS	Cyclone/WS	1984
Nuremberg	Saarberg-Hoelter-Lurgi	1x100	DS	ESP	1985-86
Oberhausen	Babcock BSH	4x130	WS	ESP	1985
Offenbach	Babcock BSH	3x55	WS	ESP	1987
Pinneberg	Babcock BSH	52	DS		1987
Rosenheim	Saarberg-Hoelter-Lurgi	1x60	DS	BH	1986
Schwandorf	Lurgi	3x100	DAS	ESP	1982
Solingen	Niro Atomizer	69	DS		1987
Stapelfeld	GfE	2x120	WS	ESP	1978
Stuttgart	Ciba Geigy	3x180	WS		1989
Würzburg	Steinmueller	1x65, 1x70	DAS	BH	1984
Wuppertal	Babcock BSH	2x100	WS	ESP	1976
Zirndorf	GfE, Lugar	1x25, 1x36	WS	ESP	1984, 1986-87

WS -- Wet Scrubber (i.e., 1 or 2 stages of alkali wet removal for acid gases)

DAS -- Dry Absorption System (i.e., dry sorbent injection or circulating fluid bed)

DS -- Dry Scrubber (i.e., spray dryer or semi-dry scrubber)

ESP -- Electrostatic Precipitator

BH - Baghouse (i.e., fabric filtration)

Note: 1000 scfm (at 68°F or 20°C) = 1580 Nm³/h (at 0°C)

TABLE 5. EFFECTIVENESS OF ACID GAS CONTROLS (% REMOVAL) (4)

Control System	Pollutant HCl	HF	SO2
Dry Injection + Fabric Filter (FF)[a]	80	98	50
Dry Injection + Entrained Fluid-Bed Reactor + ESP[b]	90	99	60
Spray Dryer Absorber + ESP	95+	99	50-70
(With Sorbent Recycle)[c]	(95+)	(99)	(70-90)
Spray Dryer Absorber + Fabric Filter	95+	99	70-90
(With Sorbent Recycle)[c]	(95+)	(99)	(80-95)
Spray Dryer Absorber + Dry Injection + ESP or FF[d]	95+	99	90+
ESP + Wet Scrubber[e]	95+	99	90+
Spray Dryer + Particulate Collector + Wet Scrubber(s)	95+	99	90+

[a] T = 160-180°C (320-356°F)

[b] T = 230°C (446°F)

[c] T = 140-160°C (284-320°F)

[d] T = 200°C (392°F)

[e] T = 40-50°C (104-122°F)

(T = the flue gas temperature at the exit of the control device.)

TABLE 6. SPRAY DRYER CONTROL OF SELECTED ORGANIC POLLUTANTS(11).

Compound	Control System (% Removal) SD + ESP	SD + FF @ High Temp.	SD + FF @ Low Temp.
Dioxins			
tetra CDD	48	<52	>97
penta CDD	51	75	>99.6
hexa CDD	73	93	>99.5
hepta CDD	83	82	>99.6
octa CDD	89	NA	>99.8
Furans			
tetra CDF	65	98	>99.4
penta CDF	64	88	>99.6
hexa CDF	82	86	>99.7
hepta CDF	83	92	>99.8
octa CDF	85	NA	>99.8

SD -- Spray Dryer
FF -- Fabric Filter
CDF -- Chlorinated dibenzofurans
ESP -- Electrostatic Precipitator
CDD -- Chlorinated dibenzo-p-dioxins